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ABSTRACT

An approach to a cost analysis of pilot, prototype, model and operational versions of the Southwest Regional Laboratory's (SWRL) Instructional Management System (IMS) is described. Five classes of systems (conceptual, pilot, prototype, model and operational) are defined, and a system development process relating classes of systems in presented. IMS functions are discussed in terms of five subsystems: data generating, communications, data processing, information storage, and report generation. Cost estimates for the communications subsystem are included. (Author/DGC)

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An approach to a cost analysis of pilot, prototype, model and operational instructional management systems (IMS) is described. Five classes of systems (conceptual, pilot, prototype, model and operational) are defined and a system development process relating the classes of systems is presented. IMS functions are discussed in terms of five subsystems: data generating, communications, data processing, information storage, and report generation. Cost estimates for the communications subsystem are included.

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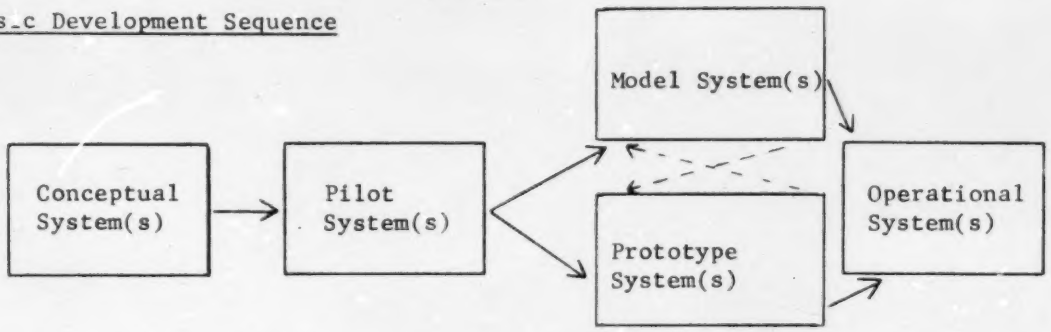
A SUGGESTED APPROACH FOR A COST ANALYSIS
OF ALTERNATIVE IMS CONFIGURATIONS

The following system development process is assumed in discussing the suggested approach to cost analysis. The system development process involves the creation of five distinctive types of systems. Figure 1 shows the basic sequence in which these systems are designed and evaluated.

Figure 1

Basic Development Sequence



A conceptual system exists only on paper or in the mind of the system designer. A number of alternative conceptual systems may be proposed (conceptual system design) for accomplishing the functional specifications of the desired operational system. The evaluation of conceptual systems may be done by logical or mathematical analysis. Proposed conceptual systems may be rejected either on the basis of feasibility or because the estimates of operational system cost are excessive. Feasibility ground-rules may vary; the designer may be limited to "off-the-shelf" components or restricted to research and development that can be completed within a fixed time period.

Pilot systems are either components of proposed operating system or a simplified version of the operating system which simulates some

aspects of the operating system's desired performance. Pilot systems may be used to test the feasibility of a conceptual system if logical analysis could provide no conclusive evidence or to reduce the uncertainty in predicting operational system costs. Pilot system evaluations are typically "quick and dirty." They rarely involve experimental designs and may be conducted in ideal or simulated environments rather than the environment in which the operational system must function.

Model systems are designed to test the effectiveness of alternative conceptual systems. Rigorous experimental designs are used to compare these systems. This may dictate that the system be tested in ideal or controlable settings rather than the environment of the operational system.

Prototype systems resemble operational systems to a greater extent than do model systems. They are evaluated in the operational or "natural" environment; thus, they should provide better information than a model system about the costs and "in-practice" deficiencies of operational systems but less information about the validity of theory concerning system effectiveness. Prototype systems serve two purposes: (1) they are used to demonstrate that the proposed operational system will work and provide accurate estimates of operational performance and costs, and (2) they can be continuously monotored, evaluated and modified to improve performance or reduce costs. These two purposes may, at times, be in conflict if the flexibility required to allow for frequent and economical modifications detracts from the system's ability to demonstrate the performance and costs of operational systems.

Operational systems function in real-world environments; control of these environments is difficult which restricts the use of experimental designs in evaluations. Evaluative research is also limited since the system tends to have less flexibility than a prototype system; it is both more difficult to monotor and more costly to modify than the prototype.

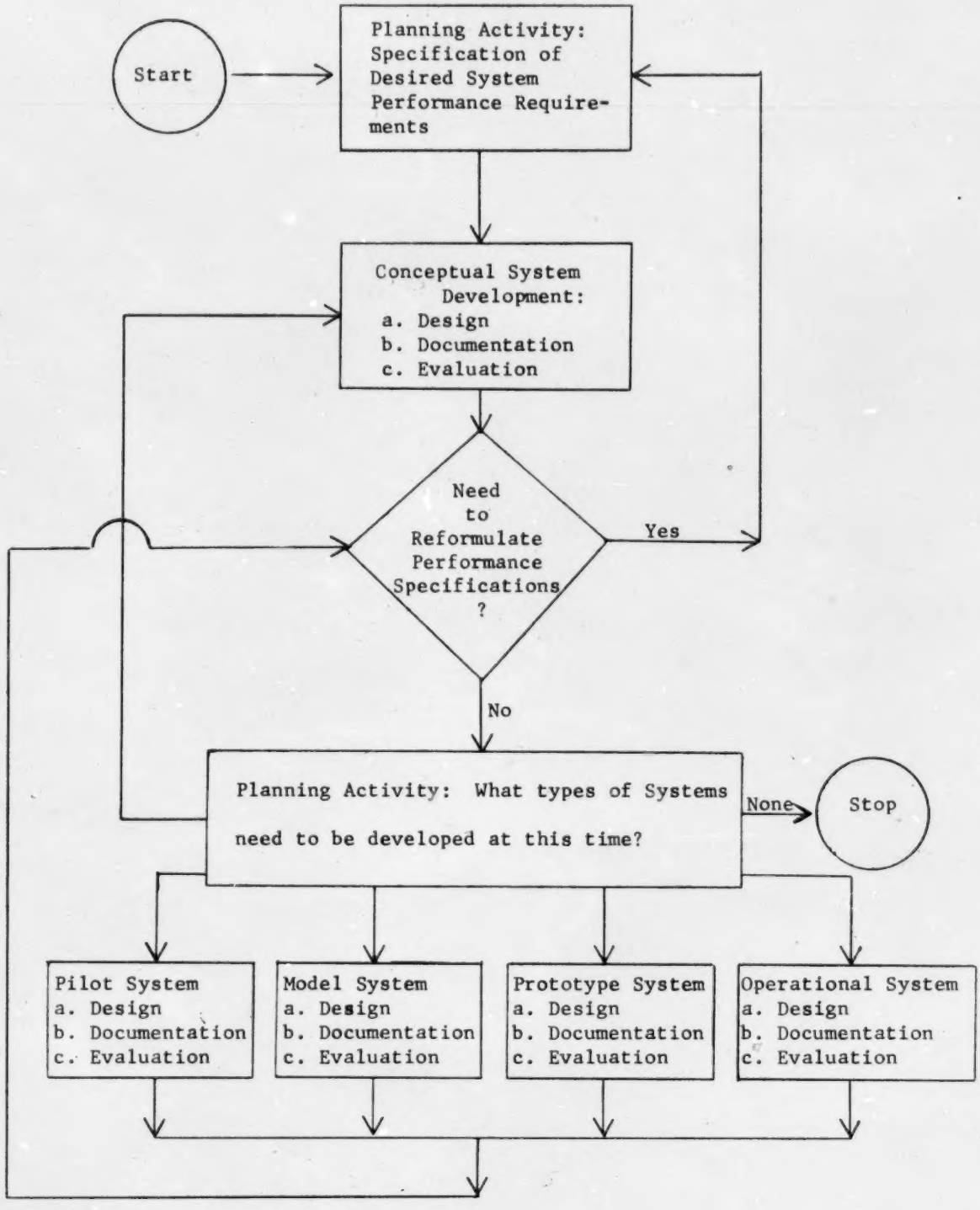
The actual process of developing an operational system is generally more complex than a sequential evolutionary chain of a conceptual system followed by a pilot system followed by model and/or prototype systems and culminating in an operational system. Figure 2 includes the planning activities, decision points and feedback paths that are needed to describe the system development process. The development of each type of system is considered to have design, documentation, and evaluation phases.

At the initiation of the system development process, it may not be feasible to specify all of the system performance requirements for the desired operational system. Pilot and model systems may be needed to supply needed information such as "what performance is needed or desirable?" and "what is the maximum permissible system cost?" The initial planning activity may involve specifying the performance requirements of a pilot system(s) that will generate this information. Model systems may be developed so that the desirability of proposed performance specifications can be evaluated by means of an experimental design.

The proposed interpretation of the system development process, as depicted in Figure 2, is that development of pilot, model, prototype, and operational systems can be done during overlapping time periods.

Figure 2

System Development Process



One purpose of the planning activity is to decide whether existing performance specifications warrant the expending of resources in a development process.

If the development of a prototype system is initiated before the performance specifications for the operational system have been completed, it should be designed to have a high degree of flexibility so that system performance for a variety of performance specifications can be simulated. Attempts to design such a flexible system may be futile and time consuming. A series of pilot systems may be more effective.

A cost analysis can be made for any of the five types of systems and at various times during the system development process. Frequent review of the projected costs and performance of the operational system can aid management in deciding at the earliest date to discontinue development or to invest resources in additional pilot or prototype systems. Cost analyses of pilot and prototype systems are useful in setting R&D priorities. The projected cost-benefits of the operational system justify the development of prototype systems. The entire development process may be viewed, in a cost analysis sense, as a systematic procedure for reducing the uncertainty in predicting the costs and performance of operational systems.

Configurations

Several hardware-software configurations have been proposed as possible operational instructional management systems. The potential software variations are infinite; only hardware configurations which are grossly different will be considered here. Three distinctly different configurations are:

(1) An optical scanner inputs data directly to a time-share, third-generation computer via phone lines with reports printed by teletypes located in participating schools.

(2) A PDP-8 computer is used as a data concentrator, receiving remote input from a number of optical scanners. Data are then transmitted via high-speed phone line to a batch-mode computer. Report information is returned to the data concentrator and later relayed to schools and printed by a teletype.

(3) The PDP-8 computer, in addition to operating as a data concentrator, performs some or all of the report generation functions of the IMS computer. The batch mode computer, if required at all, uses no remote, high-speed input.

Judging the feasibility and cost-effectiveness of these three hardware configurations requires detailed specification of the desired performance of the operational system.

System Characteristics

There are a number of characteristics of any system which greatly effect the costs of the various hardware configurations. A partial listing which is only suggestive of the total includes:

(1) The number of instructional systems, classes, and grade levels reporting input.

(2) The frequency, diversity, and quantity of data as input.

(3) The number and frequency of reports as well as the diversity of formats.

(4) The nature of output other than reports, e.g., generated material.

(5) The required turnaround time for a given input/output loop.

(6) The ability to provide output on demand

IMS Version 3

In order to provide a vehicle for the suggested approach to cost analysis, the characteristics of IMS Version 3 will be used. IMS Version 3, although capable of handling other instructional systems and grade levels, will be tested initially with a maximum of 6 instructional systems at 2 grade levels. Input consists of pupil responses to Criterion Exercises and mid-program and end-of-program tests. Output consists in formatted reports of pupil scores by outcome, for class or group, as well as averages for class or group by outcome. Output on demand is not provided. It has the following subsystems:

(1) Data Generating

(2) Communications

(3) Data Processing

(4) Information Storage

(5) Report Generation

IMS Version 3 will be tested in a number of schools during the 71-72 school year. The data generating subsystem will consist of Unit Criterion Exercises for SWRL instructional programs; the 690-21 DTS as described in Reference 1 will serve as the communications subsystem; the data will be processed by scoring the test and storing the test scores as a longitudinal data base; test scores will be returned to the teacher in the form of readable reports.

Cost Analysis for Unspecified Performance Requirements

Cost analysis, particularly the predicting of operational system costs, is greatly complicated when in the early developmental stages. It may be possible, however, to determine empirically the maximum cost that is permissible for a system that performs a certain function. This is frequently the approach taken in developing a product which must sell for less than some price figure if it is to be marketable. It may be possible to estimate how much a school system is willing to pay per pupil for various IMS functions. Knowledge of permissible costs can be of great value in judging whether proposed systems are feasible or whether development is warranted.

It may be desirable to develop a simulation model which will compute the costs for alternative hardware-software configurations for specified IMS capabilities. Such a model would facilitate projections of operational system performance from pilot and prototype test data and make it less important that the prototype system closely resemble operational systems. The inputs required for such a simulation model would, in addition, aid in identifying the requirements for pilot and prototype systems and the questions which must be answered in evaluation phases. This simulation model should be able to compute the costs of proposed pilot, prototype, and model systems in addition to projections of operational system costs.

Current Cost Esimtates

Cost estimates for the communications subsystem for IMIS have been made. An additional 4K of core and a larger disc than the current SWRL PDP-8 configuration were assumed to give the system the capability for testing the third proposed IMS configuration. The data generating, data processing and information storage costs are not included since the information required to make reasonable estimates of these costs is not available at this time.

The communications subsystem considered consists of the following components:

1. Model 12 Op-Scan input devices
2. Teletype Corporation (ASR 33) teletypes with send and receive capability
3. PDP-8/E Computer with 10 low-speed I/O ports and one high-speed I/O
4. Telephone line data links with Bell 103A full duplex modems

Table 1 contains estimates of the number of pupil tests that can be processed by the communication system in a working day. Computations were made for two standard input forms. The first form is a student test sheet which contains six multiple choice questions. The second form is a separate answer sheet containing the answers from four, six-question test sheets. The following assumptions were made about scanner performance:

1. The document transport time for a single 8½ X 11 sheet is 5.8 seconds.

2. Each scan cycle takes .2 seconds.
3. In the image mode, 8 eleven-bit characters are transmitted for each line scanned.
4. In the darkest mark mode, 1 eleven-bit character is transmitted for each line scanned.
5. The total time required to process a sheet is the sum of:
   (a) transport time
   (b) scan time
   (c) transmission time

The total system capacity computations are based on the assumption that the "optimal" number of scanners are employed. If fewer than the "optimal" number are used for the existing average demand usage, the system's capacity is reduced.

Table 2 gives costs estimates for the equipment required, personnel, maintenance, and operating costs. Equipment costs are amortized over five years. It is assumed that all phone line charges for the data links between schools and the PDP-8 are for local, unlimited service, private lines. The following chart illustrates the additional costs incurred for schools outside the local calling area of the PDP-8 installation. These costs apply to Los Angeles County for .5 average demand scanner utilization.

Additional Message Units for 3 minute call	Annual Cost
2	776.
3	1470.
6	2920.

Table 3 gives the per pupil cost (for a single subject area) of the communication system for four average demand levels. If fewer than the "optimal" number of input units are employed or if inputs are outside the local calling area, the per-pupil costs are greater. These are lower bounds on per pupil costs. It is assumed that the average number of tests given each student is 18 for a single subject area.

TABLE 1

Number of Pupil - Tests That Can Be Processed Per Day
(10 input-output devices)

Average Demand	Optimal Number of Scanners	4 pages per-student per test 6 items per page				Separate Answer Sheet for each Pupil-Test 24 answers per page			
		Image Mode		Darkest Mark Mode		Image Mode		Darkest Mark Mode	
		No line skip	line skip	No line skip	line skip	No line skip	line skip	No line skip	line skip
.6	10	108	310	227	450	432	526	907	1,224
.5	12	90	258	189	375	360	438	756	1,020
.4	15	72	206	151	300	288	350	605	816
.3	20	54	155	113	225	216	263	454	612
Total System	Capacity	1,080	3,096	2,268	4,500	4,320	5,265	9,072	12,240

Assumptions

1. The average demand is the percentage of time a scanner is inputting data to the data concentrator averaged over scanners and time.

2. Peak demand is assumed to be 50% greater than average demand.

3. The optimal number of scanners is the maximum number for which the probability of requested I/O devices (at a peak demand time) exceeding 10 is less than .25.

4. Six-hour day.

5. 300 baud transmission rate.

Table 2

IMS Communication System Costs

		Annual Cost
I. Data Concentrator Costs		
A.. Equipment		
PDP-8/E Unit with 12K core,		
Disc with 831K words, and 2 Magnetic Tape drives.	56,940.	11,390.
High-Speed Port for IMS computer input.	1,500.	300.
Low-Speed input ports, 3 units of 4 ports each.	6,000.	1,200.
Data Concentrator modems with rotary.	5,000.	1,000.
B. Operating Costs		
Communication Costs, PDP-8 to 1108.	$65 a month	6,500.
Personnel Cost to Operate Scanners.	$3 a hour	20,000.
Personnel Cost to Operate Data Concentrator		10,000.
Operating and Maintenance for Data Concentrator		5,000.
	Sub-Total	55,390.
II. Cost for Each Scanner-Teletype I/O		
A. Equipment		
Model 12 Optical Scanner (Duplex with auto. feed)	3,700.	740.
Teletype, Receive-Send	600.	120.
Modem	350.	70.
B. Operating Costs		
Local Telephone line charges	$5 a month	50.
Teletype maintenance	$22 a month	220.
Scanner maintenance	$25 a month	250.
	Sub-Total	1,450.

TABLE 3

Annual Communication Costs Per-Pupil For Each Subject Area
Using IMS (in dollars)

Average Demand	Optimal Number of Scanners	4 pages per-student per test 6 items per page				Separate answer sheet for each Pupil Test 24 answers per page			
		Image Mode		Darkest Mark Mode		Image Mode		Darkest Mark Mode	
		No line skip	line skip	No line skip	line skip	No line skip	line skip	No line skip	line skip
.6	10	6.47	2.26	3.08	1.55	1.62	1.33	.77	.57
.5	12	6.74	2.35	3.21	1.62	1.69	1.38	.80	.59
.4	15	7.15	2.50	3.40	1.72	1.79	1.47	.85	.63
.3	20	7.81	2.73	3.72	1.88	1.95	1.60	.93	.69

See Table 1 for assumed conditions.

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Crocker, Jack "Hardware Aspects of IMS Communication System," SWRL Report TN 5-70-08, June 26, 1970.

Collins, Thomas F. "A Study of Computer Configurations for Instructional Management System," SDC Report TM - 4508, February 28, 1970.